(12) LEVEL III

AD

AD-E400 762

AD A111286

TECHNICAL REPORT ARLCD-TR-81015

COMPARISON OF CLOSED BOMB TESTING AND ACTUAL FIRING OF M1 MULTIPURPOSE PROPELLANT

C. LENCHITZ

L. SHULMAN

R. F. YOUNG

DECEMBER 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report ARLCD-TR-81015

2. GOVT ACCESSION NO.
AD-A111 286

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
COMPARISON OF CLOSED BOMB TESTING AND ACTUAL FIRING OF M1 MULTIPURPOSE PROPELLANT

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
C. Lenchitz
L. Shulman
R. F. Young

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
ARRADCOM, LCWSL
Applied Sciences Div (DRDAR-LCA-G)
Dover, NJ 07801

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
ARRADCOM, TSD
STINFO Div (DRDAR-TSS)
Dover, NJ 07801

12. REPORT DATE
December 1981

13. NUMBER OF PAGES
32

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Closed bomb
Burning rate
Propellant force
Closed bomb modification
Absolute quickness
Relative quickness
Gun velocity
Gun codes
Ignition-gun velocity
Ignition-quickness
Gun velocity-quickness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effect of ignition, packaging, and initial surface area is examined for M1 propellant of varying lengths with the same composition and geometry. Quickness values are found to correlate with initial surface area and appear to relate to observed projectile velocities when modified closed bomb procedures are used.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

ACKNOWLEDGEMENT

The authors wish to thank Dr. T. Vladmiroff and L. Schlosberg, LCWSL, for helping with the closed bomb calculations, and S. Einstein, LCWSL, and F. Virginia, MISD, for the IRIS calculations.

SUMMARY

The sensitivity of closed bomb testing to differences in propellant surface area is described. The surface area of three M1 multi-perforated propellants (M1 MP), identical in composition and cross-sectional geometry, is adjusted by varying grain length, i.e., 0.508 cm, 1.156 cm and 2.471 cm. Excellent agreement is obtained with zone 7, 155-mm howitzer firings when using a modified closed bomb technique with the charge confined and the ignition expedited. Quickness values for the three charges between 6.895 MPa and 20.68 MPa correlate well with initial surface area. Average closed bomb values of $5.58 \pm 0.05 \times 10^3$, $5.09 \pm 0.08 \times 10^3$ and $4.49 \pm 0.04 \times 10^3$ MPa per second were obtained, matching 155-mm zone 7 gun velocities of 577.3 ± 2.1, 567.5 ± 2.4 and 560.5 ± 0.9 meters per second, respectively. Results from standard closed bomb measurements are similar to zone 5 firings; differences in propellant surface area did not affect closed bomb or gun firings. IBIS code calculations (using standard closed bomb data) also gave inconclusive results. The analysis demonstrates the importance of ignition in the ballistic cycle and the increased potential of closed bomb testing in correlating gun velocities.

CONTENTS

TABLES

FIGURES

INTRODUCTION

The search for a laboratory ballistic assessment test for propellants continues despite difficulties in testing techniques and limitations encountered with models which relate laboratory test data to gun performance.

Several years ago under MMT Project 5754186 (Autocap), three lots of M1 propellant, J, K, and L, distinguished only by length of grain, were subjected to standard closed bomb testing to determine the degree of discrimination of that test. Firings conducted at both Radford and ARRADCOM, Dover, NJ, show that grain length does not always affect closed bomb quickness measurements. Firings of 155-mm guns at zone 5 are also insensitive to grain length, but firings at zone 7 show significant differences in velocity. The results of this program were recently reviewed in the Progress in Astronautics Publication by AIAA "Interior Ballistics of Guns" (ref 1), but no attempt was made to explain the differences between zone 5 and zone 7 firings.

This report shows why propellant lots J, K, and L could not be differentiated using standard closed bomb techniques, and how the closed bomb method can be modified to show differences in a given propellant composition when only the grain length (or surface area) is varied. Although the effect of surface area on both closed bomb quickness and gun velocity is small compared with propellant properties such as composition (refs 1 and 2), even small differences can be detected by improving closed bomb techniques. As a consequence a good correlation between the closed bomb results and the gun firing results is obtained, and differences in gun velocity due to propellant geometry are reflected in corresponding differences in closed bomb quickness values.

EXPERIMENTAL

Samples

The chemical and physical properties of the propellants tested are listed in table 1. These analyses were made at Radford using standard procedures. The three propellants show no significant difference in chemical composition; only the grain length is varied. Calorific values are based on replicate measurements where the difference between measurements in all instances is less than 1%.

Procedure

The standard closed bomb tests were conducted in accordance with the procedure outlined in reference 3, in which the charge is bagged in a 3-mil-thick polyethylene bag with the igniter in the center of the charge. The bag ruptures as soon as the black powder is ignited. The data acquisition system is described in reference 4. All measurements were made in a 200 cm^3 closed vessel maintained at 21°C (70°F). In addition to the standard procedures, two series of tests

Table 1. Laboratory analysis of M1MP propellant lots

Composition	J	K	L
NC	85.17	85.07	85.20
DNT	9.65	9.69	9.73
DBP	5.18	5.24	5.07
(DPA)	1.04	1.06	1.05
(K_2SO_4)	0.99	1.27	1.16
TV	1.16	0.96	1.30
RS	0.56	0.36	0.80
H_2O	0.60	0.60	0.50
Physical properties			
Density (g/cm^3)	1.5553	1.5420	1.5637
Screen den	0.8079	0.7818	0.6745
Hygroscopicity (%)	0.45	0.44	0.43
Length (cm)	0.508	1.156	2.471
Dia (cm)	0.485	0.494	0.500
Length var (%)	4.10	0.84	0.90
Perf	0.0384	0.0394	0.0404
Av web (cm)	0.0968	0.0968	0.0965
L:D ratio	1.05	2.34	4.95
D:d ratio	12.69	12.53	12.37
Standard closed bomb results			
Relative quickness*	98.07	98.97	99.10
Relative force	100.92	100.98	99.93
Calorific value (cal/g)	762.0	760.0	760.0

*Compared to Std RAD 68308

were conducted in which the propellant charge was loaded into a 65 cm^3 capacity polyethylene bottle* (3.81 cm (1-1/2 in.) o.d. x 6.35 cm (2-1/2 in.) long). The actual volume of the polyethylene material is 5 cm^3. The igniter, positioned in the center of the propelling charge, is the same as that used in standard tests and consists of an M100 electric match and 1 gram of Class 7 black powder. (The grains are not oriented.) the igniter wires are led through two small tight-fitting holes in the plastic cap. The bottle with the charge is loaded into the closed bomb and fired in accordance with standard procedures. The instrumentation used to record the data is the same as that used for standard closed bomb tests. It is estimated that the bottle ruptures at approximately 1.378 MPa (200 psi). The linear burning rates are calculated according to the procedures outlined in reference 3.

RESULTS

The chemical analysis and the Q values show that the only major difference in the samples is grain length. Sample J is 0.5 cm (0.2000 in.) long and K and L are 1.156 cm (0.4551 in.) and 2.47 cm (0.9729 in.) in length, respectively. A slight difference in density is also apparent: L has the highest density, 1.564 g cm^{-3} and the density of J and K are 1.555 g cm^{-3} and 1.542 g cm^{-3}, respectively (table 1). There is no significant difference in either relative quickness or relative force [based on maximum pressure (Pmax)] among J, K, and L using standard closed bomb procedures.

The total surface area of each propellant lot as a function of distance burned is listed in table 2 and plotted in figure 1. The area of J exceeds that of K up to approximately 0.028 cm (0.011 in.) of burning. Beyond that, the area of K is larger. The surface area of L begins to exceed that of J at 0.036 cm (0.014 in.). A comparison of K and L shows that the surface area of K exceeds L up to 0.043 cm (0.017 in.), or just before burnout. Assuming equal linear burning rates for the three propellants, the following order of absolute quickness (dp/dt) is anticipated from the time of ignition well into steady state burning: J> K> L. This order is not manifested at either 0.2 loading density (LD) or 0.37 LD in standard closed bomb testing (table 3). The unsmoothed quickness values in table 3 were obtained between 6.89 MPa (1,000 psi) and 20.68 MPa (3,000 psi) by estimating the time closest to the two pressure extremes. The smoothed values are obtained at 13.79 MPa (2,000 psi) from the equation $dp/dt = mp + b$, and includes all quickness values (taken each 32 μs) from the computer readout between 6.89 and 20.68 MPa. The smoothed values are, in all instances, larger than the unsmoothed values because the latter represents the quotient of the total pressure interval divided by the time interval, i.e.,

$$\frac{20.68\ \text{MPa} - 6.89\ \text{MPa}}{\Delta t}$$

*Nalgene Bottles, narrow mouth.

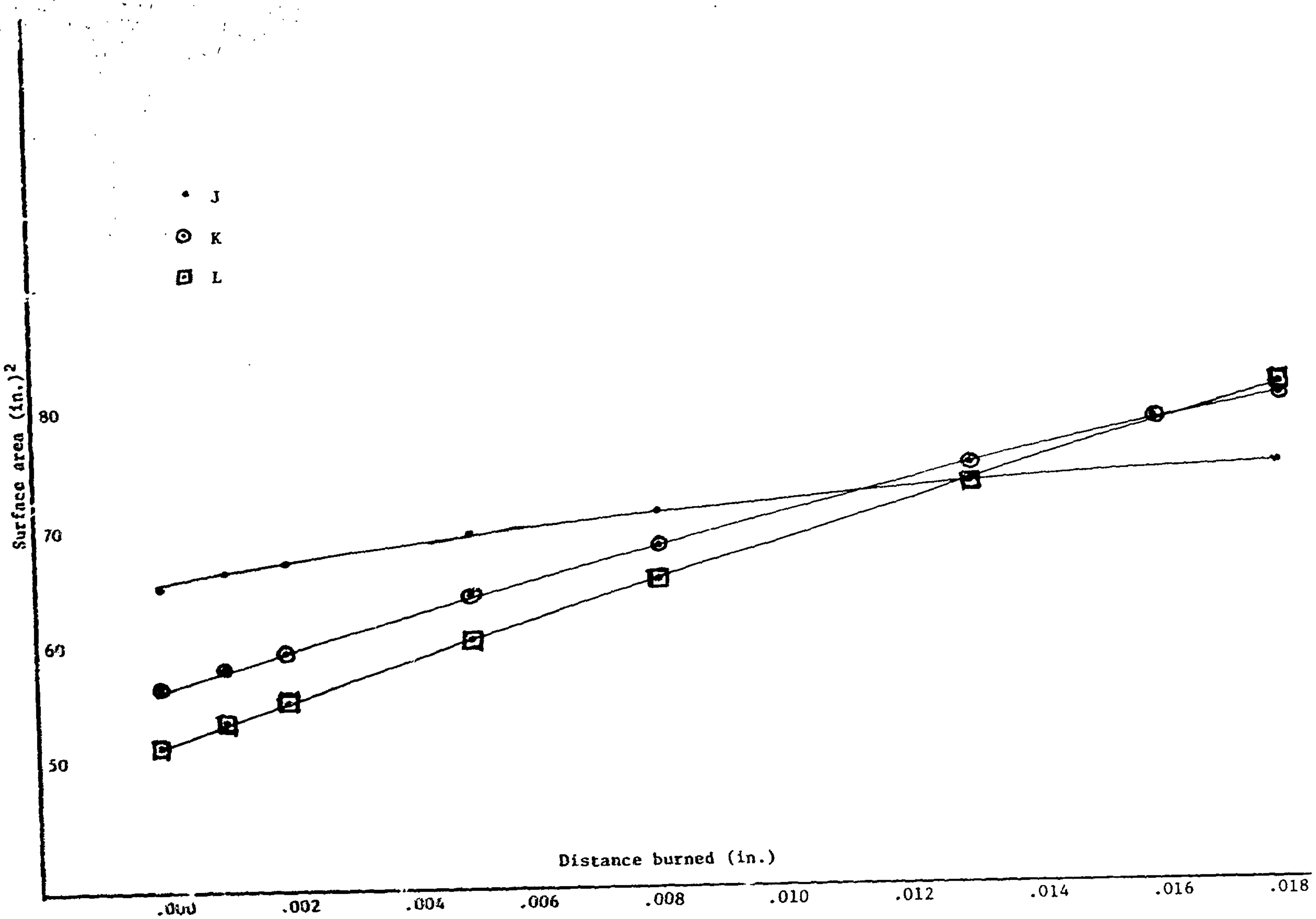

Figure 1. Surface area of J, K, and L vs distance burned (in.)^2

Table 2. Total surface area of J, K, and L vs distance burned at 0.2 LD
10^2 cm^2

Distance burned (cm)	Propellant lots J	K	L
0.000	65.99	57.37	52.72
0.00254	67.00	58.92	54.45
0.01270	70.43	64.86	61.22
0.02540	73.32	71.68	69.42
0.03810	74.67	77.84	77.33
0.04572	74.74	81.22	81.93

Table 3. Absolute quickness of M1MP propellant J, K, L between 6.89 MPa and 20.68 MPa (three-shot series)*

		10^3 MPa per sec J	K	L
I	Std (unsmoothed A to D data 6.89 to 20.68 MPa + Δt 0.2 LD)	4.11 ± 0.35	3.05 ± 0.36	3.03 ± 0.23
	Smoothed data at 13.79 MPa (dp/dt = mp + b)	4.61 ± 0.33	3.73 ± 0.46	- -
II	Std (unsmoothed A to D data 6.89 to 20.68 MPa + Δt, 0.37 LD	11.19 ± 0.25	8.80 ± 0.56	8.71 ± 0.21
III	Confined charge, 0.2 LD (unsmoothed data 6.89 to 20.68 MPa + Δt)	5.21 ± 0.01 5.04 ± 0.19	4.59 ± 0.05 4.58 ± 0.23	4.00 ± 0.03 4.01 ± 0.06
IV	Confined charge, 0.2 LD smoothed data at 13.79 MPa (dp/dt = mp + b)	5.57 ± 0.05 5.58 ± 0.06	5.07 ± 0.01 5.10 ± 0.15	4.47 ± 0.03 4.51 ± 0.05
V	% Increase confined-std unsmoothed	24.83	50.34	31.[illegible]
	smoothed	21.00	36.00	- -

*Corrections were not made for the initial 5 cm^3 occupied by the plastic bottle in the confined charges.

Here, unlike the smoothing procedure, the larger increases in dp/dt which occur as 20.68 MPa is approached are obscured.

Unlike the standard conditions, however, confinement in plastic containers gives significant differences in dp/dt in the anticipated order, i.e., dp/dt J> K> L (III and IV, table 3). Beyond 20.68 MPa and up to 172.4 MPa (25,000 psi), there is no significant difference in dp/dt among any of the samples. The details of the latter results are summarized in reference 5.

Firing in the 155-mm howitzer are similar to these closed bomb results. Table 4 shows that in zone 5 there are no significant differences in velocity in any of the three propellant lots. In zone 7, however, the differences are significant. The velocities of J, K, and L are 577.3, 567.5, and 560.5 meters per second (1,894 $\pm$ 7, 1,862 $\pm$ 8, and 1839 $\pm$ 3 fps), respectively (ref 1 and 6).

Table 4. Gun velocities of M1 propellant lots J, K, and L in 155-mm howitzer

Lot	Zone 5[a] average velocity (m/s)	Zone 5 average pressure (MPa)	Zone 7[b] average velocity (m/s)	Zone 7 average pressure (MPa)
J	382.5 $\pm$ 3.4	97.2 $\pm$ 4.9	577.3 $\pm$ 2.1	286.1 $\pm$ 8.3
K	381.9 $\pm$ 2.7	96.5 $\pm$ 3.7	567.5 $\pm$ 2.4	258.7 $\pm$ 6.7
L	380.1 $\pm$ 3.4	92.6 $\pm$ 4.6	560.5 $\pm$ 0.9	237.6 $\pm$ 2.9

[a]Zone 5 charge wt = 3.198 kg
[b]Zone 7 charge wt = 6.021 kg

In the M4A2 propelling charge the major differences between zones 5 and 7 are charge weight and free volume. The latter has a significant effect on the initial pressure and pressure build-up (dp/dt) which, in turn, determines the ignition and subsequent burning of the propellant. For an M1 propellant the initial pressure is crucial to ignition (ref 7). In order to effect a higher initial pressure and a more uniform and rapid ignition, an attempt was made to simulate zone 7 conditions in the closed bomb by confining the sample in the plastic bottle, and igniting it in the center (as described above). The confinement of the charge enhances ignition and provides a shot start simulation. The results obtained are summarized in III and IV, table 3 and the details listed in table 5. To assure confidence, the two series of tests were conducted one month apart, 75-08 and 75-09.

Table 5. Absolute quickness MPa/s at 13.79 MPa using all points between 6.89 and 20.68 MPa for equation dp/dt = MP + b

(10^3 MPa sec^{-1})

	J		K		L	
DATE	75-08	75-09	75-08	75-09	75-08	75-09
	116.6	116.3	106.6	110.5	93.8	93.7
	118.4	117.2	106.9	104.0	91.8	95.1
	116.8	118.9	106.6	107.2	93.4	95.6
	117.2 ± 1.07	117.5 ± 1.3	106.7 ± 0.1	107.2 ± 3.2	93.9 ± 0.5	94.8 ± 1.0

Two significant changes are effected by confining the charge: the quickness between 6.89 MPa and 20.68 MPa for J, K, and L is increased 25%, 50%, and 32%, respectively (which is well beyond the initial 5 cm^3 reduction in bomb volume caused by the bottle), and a significant difference in quickness among the three lots is readily apparent. Table 3 shows that under standard conditions quickness values for J, K, and L are 4.11 x 10^3 MPa/s, 3.05 x 10^3 MPa/s, and 3.03 x 10^3 MPa/s (596 x 10^3, 443 x 10^3 and 440 x 10^3 psi/s) and, by confining the charge, the values are increased to 5.12, 4.58 and 4.00 MPa/s, respectively, (744 x 10^3, 666 x 10^3, and 580 x 10^3 psi/s). The good relationship between confined closed bomb testing and zone 7 gun velocity is shown in figure 2.

Linear burn rates calculated from confined closed bomb firing (table 6) are used in the IBIS gun code calculations (table 7). The code velocity values are not in accord with gun firings. In both zones 5 and 7, the velocities of J and K are equal; only that of L is significantly lower. Assuming that the burning rate of all samples is the same, the IBIS calculation gives only small differences in velocity among the three samples (table 7).

The effects of confining double and triple base propellants are compared in tables 8 and 9. For M26 propellant the bottle causes an increase in quickness in the low pressure range (2% to 8% Pmax) of only 4.45%, i.e., 7.28 ± 0.13 versus 6.96 ± 0.07 x 10^3 MPa/s. From 8% to 80% Pmax the increase is 11.5%, i.e., 44.35 ± 0.59 x 10^3 MPa/s versus 39.76 ± 0.25 x 10^3 MPa/s (table 8).

At low pressure where ignition is difficult the M30, like the M1 propellant, under confined closed bomb firings gave significantly higher dp/dt values than the standard unconfined firings, i.e., $4.70 \pm 0.$[illegible]3 MPa/s versus 3.85 ± 0.28 MPa/s, respectively, for the 2% to 8% range. Between 8% and 80% Pmax values are 28.4 ± 0.2 versus 26.1 ± 0.3 MPa/s, an increase of 1[illegible]%.

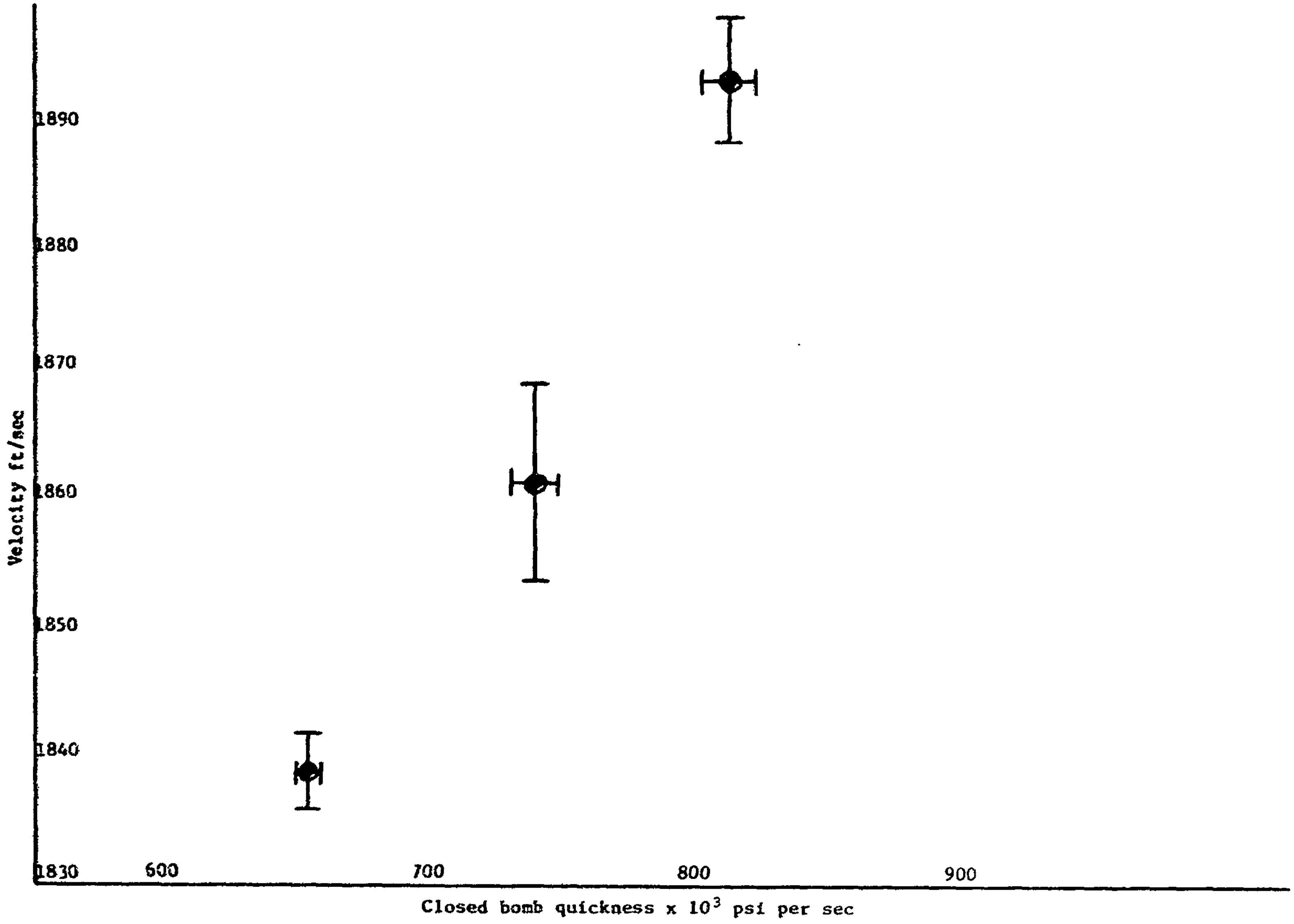

Figure 2. Relationship between confined closed bomb quickness values and 155-mm velocities

Table 6. Linear burning rates of 0.2 LD samples burned in plastic bottles

Pressure		cm/s					
		J		K		L	
MPa	(psi)	75-08	75-09	75-08	75-09	75-08	75-09
13.79	(2,000)	1.50 $\pm$0.02	1.44 $\pm$0.03	1.52 $\pm$0.01	1.49 $\pm$0.06	1.19 $\pm$0.01	1.19 $\pm$0.01
34.47	(5,000)	2.91 $\pm$0.02	2.86 $\pm$0.04	3.02 $\pm$0.01	2.98 $\pm$0.06	2.52 $\pm$0.02	2.52 $\pm$0.01
68.95	(10,000)	4.81 $\pm$0.01	4.81 $\pm$0.02	5.06 $\pm$0.01	5.03 $\pm$0.03	4.43 $\pm$0.04	4.43 $\pm$0.01
103.42	(15,000)	6.46 $\pm$0.01	6.52 $\pm$0.01	6.86 $\pm$0.02	6.84 $\pm$0.02	6.17 $\pm$0.06	6.18 $\pm$0.02
137.90	(20,000)	7.96 $\pm$0.03	8.09 $\pm$0.06	8.50 $\pm$0.05	8.50 $\pm$0.07	7.80 $\pm$0.09	7.82 $\pm$0.04
	b	2.374×10^{-3}	1.87×10^{-3}	2.050×10^{-3}	1.896×10^{-3}	9.436×10^{-4}	9.349×10^{-4}
	n	0.7257	0.7510	0.7469	0.7562	0.8167	0.8179

Table 7. Results of IBIS calculations[a]

	STD	J	K	L
Zone 5				
Charge weight (kg)	3.198	3.198	3.198	3.198
Web (mm)	0.853	0.968	0.968	0.965
Velocity (m/s)	371.8	363.3	363.9	339.8
Pressure (MPa)	84.8	78.0	79.3	61.4
Time to peak pressure (m/s)	7.05	7.16	7.55	8.26
Zone 7				
Charge weight (kg)	5.981	5.981	5.981	5.981
Web (mm)	0.853	0.968	0.968	0.965
Velocity (m/s)	536.9	553.8	554.7	539.2
Pressure (MPa)	251.0	239.2	251.0	210.3
Time to peak pressure (m/s)	5.19	4.96	5.21	6.33

IBIS velocities assuming all properties including burning rate are equal and only grain lengths are different[b]

Sample	Velocity (m/s) Zone 5	Zone 7
J	395.6	596.2
K	392.9	592.2
L	391.4	590.4

[a]Calculations by S. Einstein
[b]Calculations by F. Virginia

Table 8. Absolute quickness M26 RAD 67268 confined vs unconfined closed bomb values 0.2 LD*

(10^3 MPa per sec)

2% to 8%		8% to 80%	
Confined	Unconfined	Confined	Unconfined
7.05	6.96	43.82	39.51
7.34	6.870	44.10	39.60
7.42	6.96	44.20	39.94
7.30	7.05	44.26	40.00
7.28	6.96	44.35	39.76
±0.13	±0.07	±0.59	±0.25

% Increase = 4.45 % Increase = 11.5

*Corrections were not made for the 5 cm^3 initially occupied by the plastic bottle in the confined charge.

Table 9. Absolute quickness M30 RAD 68945 confined vs unconfined closed bomb values 0.2 LD*

(10^3 MPa per sec)

2% to 8%

Unsmoothed data		Smoothed data	
Confined	Unconfined	Confined	Unconfined
4.51	4.01	5.25	3.32
4.60	4.23	4.38	4.20
4.32	3.31	4.61	4.03
5.25	3.65	4.55	___
4.67	3.80	4.70	3.85
±0.41	±0.40	±0.38	±0.28
% Increase = 23.05		% Increase = 22	

8% to 80%

Unsmoothed data		Smoothed data	
Confined	Unconfined	Confined	Unconfined
29.1	26.1	28.0	25.8
28.4	26.1	28.2	26.4
28.8	25.9	28.3	26.1
28.3	26.2	29.1	___
28.7	26.1	28.4	26.1
±0.4	±0.1	±0.2	±0.3
% Increase = 10.00		% Increase = 9	

*Corrections were not made for the initial 5 cm^3 occupied by the plastic bottle in the confined charge.

In the quickness calculations, smoothing the data by assuming linearity between the specified pressures and calculating a least-squares equation, i.e., $dp/dt = mp + b$, did not give lower standard deviations than the unsmoothed data, where estimates of the time are made between two successive readings below and above 6.89 MPa and 20.68 MPa, respectively.

The effect of confinement on Pmax for all samples is shown in table 10. Increases in pressure of 1.5% to 2.7% (table 10) are obtained for the M1 samples and larger increases are recorded for the M26 and M30 propellants, i.e., 6.9% and 5.4%, respectively. Assuming the bottle to be inert, an increase of 2.5% is anticipated. The larger increases in the M26 and M30 are attributed to the higher oxygen balance which may cause the partial burning of the plastic with the formation of gases of low oxygen content, i.e.,

$$O_2 + COHN \dashrightarrow N_2O + CO + H_2O$$

Table 10. Effect of plastic bottle on Pmax values

Sample	Confined (plastic bottle) MPa	Confined (plastic bottle) (psi)	Standard MPa	Standard (psi)	Increase %
M1					
J	(224.77)	32,600 ± 200	(219.53)	31,840 ± 308	2.39
K	(224.36)	32,540 ± 293	(218.36)	31,670 ± 100	2.67
L	(220.91)	32,040 ± 243	(217.60)	31,560 ± 234	1.52
M26	(281.42)	40,816 ± 177	(263.35)	38,196 ± 133	6.86
M30	(270.68)	39,259 ± 177	(256.00)	37,235 ± 14	5.44

DISCUSSION

The difficulty in predicting gun ballistics from closed bomb measurements can be realized readily when one notes that, even in the same M1A1 155-mm howitzer, velocities cannot be extrapolated from firings made at zone 5 to those made at zone 7. This is evident in table 4 which shows that the muzzle velocities of propellant lots J, K, and L are not significantly different at zone 5, but increase incrementally with propellant surface area at zone 7 (refs 1 and 8).

For a given propellant the zone 7 charge is twice the weight of the zone 5 charge, (the igniter is the same for each zone). This causes a major difference in loading density. In zone 7 where the void volume is approximately one-half that of zone 5 and the grains are more tightly packed, ignition is quicker because of the more rapid pressure buildup by the igniter and the larger total surface area. This expedites the ignition-combustion transition. Table 11, which is an extract of a typical 155-mm firing curve, is a good example of this. (Details of the gun firings for J, K, and L were not obtained.) In the low pressure region, where ignition takes place, it takes 12.05 ms to reach 4.83 MPa in zone 5 and only 2.55 ms to reach the same pressure in zone 7.

Table 11. Comparison of pressure-time data at zones 5 and 7

155-mm howitzer (M4A2 charge)*

Pressure		Time (m/s)	
MPa	(psi)	Zone 5	Zone 7
4.83	(700)	12.05	2.55
6.89	(1,000)	12.90	3.30
10.34	(1,500)	13.80	3.77
20.68	(3,000)	15.05	4.58
34.47	(5,000)	16.20	5.09
68.95	(10.000)	18.60	5.90

*Std RAD 68308

The prolonged ignition at zone 5 may consequently mask the effect of the surface area. When the void is large, the grains are not a coherent mass (immediately after ignition), the ignition combustion transition is prolonged, and the difference in surface area is obscured by the large heat loss and the long period of time required to establish a reaction chemistry in which the products do not change significantly with pressure (ref 9).

These factors are reflected in both the pressure and the velocity measurements made in the gun for propellant lots J, K, and L, which show no significant difference among the propellants in either parameter at zone 5. In zone 7, however, Pmax of the three propellants correlates well with the magnitude of the surface area and muzzle velocity, and pressures of 286.1 MPa, 258.7 MPa, and 237.6 MPa are generated, with corresponding velocities of 577, 568, and 560 m/s, respectively, table 4.

In standard closed bomb tests, the propellant sample is not confined. If it is packaged at all, it is usually placed in a bag which offers no resistance to any pressure developed by the igniter. The conditions are, consequently, similar to those encountered at zone 5 firings. Confinement of the propellant in a plastic bottle, on the other hand, reduces the volume during ignition until a pressure of 1.4 MPa is attained, at which point it ruptures. Laboratory experiments in an arc image furnace and with black powder show that an initial pressure of 1.4 MPa provides an excellent environment for the rapid ignition of M1 propellant (ref 7).

The confinement enhances the differences in surface area among lots J, K, and L and increases the dp/dt values of all the samples up to 50% between 6.89 and 20.68 MPa. Absolute values of 117, 107, and 94 x 10^3 MPa/s are obtained, which are in accord with zone 7 velocities (fig. 2). These data demonstrate the significance of ignition in both the closed bomb and the gun.

Confinement is not always necessary to distinguish differences in surface area in the closed bomb. Domen (ref 8) reports the results for two other M1MP propellants used in the 155-mm howitzer. Propellants P and R are similar in

Comparison of closed bomb quickness and gun velocity
(M1MP propellants P and R)

Propellant	Length L(cm)	Dia D(cm)	Perforation (cm)	Web avg (cm)	Relative quickness* (%)	Surface area per kg (cm 2)	Velocity Zone 5 (m/s)	Velocity Zone 7 (m/s)
P	1.328	0.604	0.0592	0.107	90.1	8.56 x 10^3	358.7	556.2
R	1.001	0.447	0.0427	0.0808	119.0	11.58 x 10^3	400.0	590.7

*Std RAD 68307 8

composition but each is low in volatile and sulfate content. Their Q values are identical, 766 cal g^{-1}; these are >1% higher than the Q values of J, K, and L. The primary difference between P and R, as compared with J, K, and L, is geometry and surface area in addition to lower volatile and sulfate content. The following table shows a significantly larger difference in initial total surface area between P and R than between any of the two samples in the J, K, L group. Thus in zone 5 the difference in total surface area between P and R is 0.92 m^2 whereas the largest difference in the J, K, L group is 0.55 m^2. In zone 7 the difference is 1.74 m^2 and 1.03 m^2, respectively.

Comparison of initial total surface area of M1MP propellant

Zone	Area (m^2) J	K	L	P	R
5	3.42	3.09	2.87	2.78	3.70
7	6.44	5.82	5.41	5.23	6.97

In 40 g closed bomb firings (0.2 LD), the difference in initial surface areas is 116 cm^2 between P and R and only 69 cm^2 between J and L. The 33% difference in surface area between P and R in standard closed bomb firings results in a 32% difference in relative quickness. In confined firings of the J, K, and L series we obtain a similar correlation: a difference in surface area of 11% (J and K) gives a 10% difference in dp/dt; the difference of 19% in surface area between J and L results in a 25% difference in dp/dt.

Relationship of surface area to velocity

Propellant lot	Percentage of difference: Area	dp/dt	Velocity Zone 5	Velocity Zone 7
J and K	11	10	--	2
J and L	19	25	--	3
R and P	33	32	10	6

The effect of surface area on velocity is not as large as on dp/dt, because propellant force, heat loss, etc. have a larger effect on the final velocity.

The porosity of the propellant bed must be considered in resolving differences between the J, K, and L series and the P and R series of propellants in both the closed bomb and the gun. When the length, geometry or any other physical dimension of the grain is changed, the bed porosity is also affected. In the pressure region of ignition, dp/dt is not only a function of surface area, volume, burning rate and heat loss, but also porosity. The latter is an unknown quantity, particularly under the dynamic conditions encountered during ignition.

Models are also limited because of the complications arising during ignition. The IBIS model (ref 6), which combines first principles and gun firings, predicts that propellant lot L will give lower velocities than J and K, but shows negligible differences between J and K. If the measured physical properties,

closed bomb burning rates and force values are not used, and it is assumed that J, K, and L are alike in all respects except grain length, the IBIS code gives small equivalent differences (less than 1%) among samples in both zones (table 7).

In empirical models, where the increase in muzzle velocity (ΔMV) for a specific gun and charge can be correlated with relative quickness and relative force, i.e.,

$$\Delta MV = k_1 \Delta RQ + k_2 \Delta RF \text{ where } k_1 \text{ and } k_2$$

are constants, the low pressure region of ignition is also overlooked.

The effect of confinement on M30 propellant is somewhat similar to that of M1. In the low pressure range (2% to 8% Pmax), a 26% increase in quickness is recorded; between 8% and 80% Pmax the increase is 10%. Confined M26, a double-base propellant, shows an increase in quickness of only 4% in the low pressure range and 11.5% at higher pressures.

The differences between propellants M1 and M30, and propellant M26 may be attributed to the fact that the M1 and M30 are more difficult to ignite and that confinement expedites the ignition of the single- and triple-base propellants. This results in a higher dp/dt. The M26 (which ignites readily) requires no confinement. It is not as pressure sensitive to ignition as triple- or single-base propellants. Laboratory experiments in ignition show that doubling the weight of black powder reduces the ignition delay of M26 propellant only 6 m/s (from 33 to 27 m/s) whereas the ignition delay of M30 propellant is reduced from 130 m/s to 70 m/s. Even more pertinent is the fact that, unlike the M26, neither M1 nor M30 can be ignited by an electrically heated wire at ambient pressure. They do ignite, however, at 0.69 MPa (ref 7).

CONCLUSIONS

1. The importance of ignition in the closed bomb as well as in the gun cannot be overemphasized. The proper packaging and adjustment in granular surface area should result in higher gun velocities for a given charge weight.

2. Closed bomb measurements can be made more meaningful and more weapon relatable, by confining the charge and enhancing ignition.

3. Absolute quickness measurements can be obtained reproducibly.

RECOMMENDATIONS

1. The effect of charge confinement should be explored further using more controllable techniques. It would be worthwhile to confine charges in the closed bomb using blowout discs with different rupture pressures. (A small perforation in the disc may be required.) Prepressurization with an inert gas should also be investigated, even though laboratory experiments conducted several years ago indicated a cooling effect.

2. The results obtained from the confinement measurements should be tested in gun codes and models.

3. Porosity measurements should be made under actual ignition conditions.

REFERENCES

1. P. Serao and J. Pierce, "Sensitivity and Ballistic Performance to Propellant Combustion Properties," AIAA Journal, Progress in Astronautics, "Interior Ballistics of Guns," edited by H. Krier and M. Summerfield, Vol 66, 1979, p 259.

2. M. Benreuven and M. Summerfield, "Applicability of Relative Quickness as a Precision Measure of Muzzle Velocity," AIAA Journal, Progress in Astronautics," Interior Ballistics of Guns," edited by H, Krier and M. Summerfield, vol 66, 1979.

3. A. O. Pallingston and M. Weinstein, "Method of Calculation of Interior Ballistic Properties from Closed Bomb Data," Picatinny Arsenal Technical Report 2005, June 1954.

4. L. Scholosberg and L. Shulman, "An Automated Method for Reduction of Closed Bomb Data for Gun Propellants," 9th JANNAF Combustion Meeting, CPIA Publication, vol 2, September 1972, pp 11-15.

5. L. Shulman, C. Lenchitz and R. F. Young, Lab Report 75-FR-Q-P-12, Picatinny Arsenal, Dover, NJ, 17 September 1975.

6. F. A. Taverni and A. G. Edwards, "IBIS Interior Ballistics Interactive Simulation," MISD 78-5, ARRADCOM, Dover, NJ, March 1978.

7. C. Lenchitz, B. Haywood, E. Hayes and L. Bottei, "Comparison of Black Powder and Purely Thermal Sources in the Ignition of Standard Propellants," Proceedings of 16th JANNAF Combustion Meeting, 1979, p 169.

8. J. K. Domen, "Modernization of Closed Bomb Testing for Acceptance of Single Base Propellant," Report No. SARPA-QA-016, Picatinny Arsenal, Dover, NJ, March 1976.

9. C. Lenchitz and B Haywood, "Determination of the Role of the Ballistic Modifier in Propellant Combustion Using the Heat of Explosion Test," Combustion and Flame, vol 10, no. 2, June 1966.

DISTRIBUTION LIST

Commander
U.S. Army Armament Research and
  Development Command
ATTN: DRDAR-GCL
  DRDAR-LC, J. Frasier
  DRDAR-LCA, H. Fair
  DRDAR-LCA-G, L. Bottei
    A. Bracuti
    T. Vladimiroff
    S. Westley
    D. Downs (2)
    K. Russell
  DRDAR-LCE, J. Picard
  DRDAR-LCS-D, K. Rubin
  DRDAR-LCU, A. Moss
  DRDAR-LCU-CA, D. Costa
  DRDAR-LCS-D, R. Corn
  DRDAR-LCU-CT, E. Barrieres
  DRDAR-LCU-CP, R. Reisman
  DRDAR-QA, J. Rutkowski
    J. Domen
    G. Silvestro
    F. Fitzsimmons
  DRDAR-SC, B. Brodman
    L. Stiefel
    F. Serao
  DRDAR-TSE-O
  DRDAR-TSS (5)
Dover, NJ 07801

Headquarters, Department of the Army
ATTN: DAMA-ARZ
  DAMA-ARZ-A, M. Lasser
    E. Lippe
  DAMA-CSM
  DAMA-WSW
The Pentagon
Washington, DC 20301

Chief
Benet Weapons Laboratory, LCWSL
U.S. Army Armament Research and
  Development Command
ATTN: DRDAR-LCB-TL
Watervliet NY 12189

Commander
U.S. Naval Surface Weapons Center
ATTN: M. Shamblen
J. O'Brasky
C. Smith
Dahlgren, VA 22448

Commander
U.S. Naval Ordnance Station
ATTN: S. Mitchell
Indian Head, MD 20640

Commander
U.S. Naval Ordnance Station
ATTN: F. Blume
Louisville, KY 40202

Commander
Armaments Development and Test Center
ATTN: AFATL, O. Heiney
Eglin Air Force Base, FL 32542

Calspan Corporation
ATTN: G. Sterbutzel
P.O. Box 235
Buffalo, NY 14221

Director
Chemical Propulsion Information Agency
Johns Hopkins University
ATTN: T. Christian
Johns Hopkins Road
Laurel, MD 20810

Commander
U.S. Army Missile Research and
Development Command
ATTN: Technical Library
Redstone Arsenal, AL 35809

Commander
U.S. Army Test and Evaluation Command
ATTN: DRSTE-AD
DRSTE-AR
DRSTE-CM-F
DRSTE-FA
DRSTE-TO-F
Aberdeen Proving Ground, MD 21005

Director
U.S. Army Ballistic Research Laboratory
ARRADCOM
ATTN: DRDAR-TSB-S
DRDAR-BL, Dr. Eichelberger
DRDAR-BLP, L. Watermeier
Aberdeen Proving Ground, MD 21005

Project Manager
Cannon Artillery Weapons Systems
ATTN: DRCPM-CAWS
Dover, NJ 07801

Director
U.S. Army TRADOC Systems
Analysis Activity
ATTN: ATAA-SL, Tech Library
White Sands Missile Range, NM 88002

Commander
U.S. Army Air Defense Center
ATTN: ATSA-SM-L
Fort Bliss, TX 79916

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22314

Director of Defense Research and Engineering
ATTN: R. Thorkildsen
The Pentagon
Arlington, VA 20301

Defense Advanced Research Projects Agency
ATTN: Director, Materials Division
1400 Wilson Boulevard
Arlington, VA 22209

Commander
U.S. Army Materiel Development and
Readiness Command
ATTN: DRCDMD-ST
DRCLDC, T. Shirata
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
U.S. Army Tank Automotive Research
  and Devcelopment Command
ATTN: DRDTA-UL
Warren, MI 48090

Commander/Director
Chemical Systems Laboratory
U.S. Army Armament Research and
  Development Command
ATTN: DRDAR-CLJ-L
      DRDAR-CLB-PA
APG, Edgewood Area, MD 21010

Director
U.S. Army Materiel Systems
  Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Commander
U.S. Army Armament Materiel
  Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61299